LOW FREQUENCY DIELECTRIC SPECTROSCOPY AS A CONDITION MONITORING TECHNIQUE FOR LOW VOLTAGE CABLE IN NUCLEAR PLANTS

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ABSTRACT

The condition monitoring of low voltage (LV) cables in nuclear power plants has historically relied on material-based examination. Recent research sponsored by EPRI evaluated the ability of low frequency domain spectroscopy (LFDS) to monitor aging in thermally aged cables. In this paper the results obtained on a thermally aged 24 conductor shielded LV control cable are presented. LFDS tests were performed on short single insulated wires and the whole cable in the 10^{-3} to 10^{6} Hz and 10^{-3} to 10^{3} Hz range, respectively. A variety of diagnostic 'metrics' derived from the variable frequency dielectric response data were trended as a function of aging time and compared to traditional material property results.

KEYWORDS

LFDS, dielectric spectroscopy, chlorososulfonated polyethylene, CSPE. Ethylene propylene rubber, EPR, indenter modulus, density, multiconductor.

INTRODUCTION

EPRI sponsored this research because of the void in electrical test techniques available to identify degradation in low voltage cables. Cable degradation can be over long lengths of a cable, but typically it is localized. dielectric spectroscopy (DS), which can be performed from the cable terminations, has been used for decades to characterize dielectric properties of a wide range of materials, especially polymers [1] . However, it remained mostly a laboratory technology until its potential to assess the condition of cable insulation materials started to be explored. Within the context of polymeric cable insulation investigation, the frequency range of interest for DS has mostly been limited to between ~10^{-3} Hz and 10^{3} Hz as this covers the dielectric relaxation phenomena of strongest interest. Low frequency dielectric spectroscopy (LFDS) is the terminology used in this paper to cover that frequency range, and to distinguish it from broadband dielectric spectroscopy, which can extend in practice to frequencies up to ~10^{12} Hz [1].

The potential of LFDS to monitor cable insulation degradation, more specifically thermal aging, was investigated in EPRI Technical Report TR-105581: [2] on single, short (approximately 10cm long), wire samples with a variety of insulation types. Non-conventional low frequency (10^{-3} Hz to 10^{4} Hz) tan δ results (obtained using time domain dielectric spectroscopy techniques) were found to change with thermal aging and measurement temperature for most types of insulation materials included in the study. The applicability of LFDS testing on multi-conductor cables was also investigated and for unshielded multi-conductor configurations, testing conductor-to-conductor was found to be a realistic alternative.

More recently, the European ADVANCE project [3] investigated a number of condition monitoring techniques on LV cables with combined thermal and radiation aging. Among the electrical techniques investigated, LFDS showed the most promising results. In particular, between 10^{-2} Hz and ~10^{6} Hz, test results on shorts single wire samples showed that both real (ε') and imaginary (ε'') parts of permittivity of XLPE, EPR-based and EPDM-based insulations increased over the whole frequency range. The variation of ε' was more evident at low frequency, while ε'' increased markedly also in the high frequency range. The change in electrical properties appeared to correlate well with traditional material-based characterization techniques. This research led to the publication of a series of papers with additional details about the work with LFDS [4, 5, 6]. Linde et al. subjected XLPE insulation to combined thermal and radiation aging under different conditions [4]. ε' and ε'' were found to increase with increasing aging. ε'' at 100 Hz in particular was found to increase linearly with the density of the material. The same team also showed that the imaginary permittivity ε'' correlated well with the material relaxation time, as measured by nuclear magnetic resonance [5]. Verardi et al. [6, 7, 8] also reported good correlation between elongation at break and the real and imaginary part of the permittivity at 10^{-2} Hz for EPR insulated cables subjected to simultaneous thermal and radiation aging.

A few other independent studies have provided more insight into the potential of LFDS for LV cables condition monitoring. Braun highlighted the sensitivity to thermal aging of dielectric loss measurements at very low frequency (10^{-2} Hz and lower) for a number of insulation materials [9]. Careful test configuration selection was noted to be important to ensure reliable and repeatable results. Chailan et al. demonstrated the applicability of dielectric spectroscopy to monitor thermal aging of EPR [10] and CSPE [11] materials. The method was also found to be able to detect changes in the insulation properties induced by irradiation [12, 13, 14]. It should be noted that most of these studies focused on the characterization of material samples (e.g. single core insulated wires, thin films/slabs), rather than practical cable samples. Recent work on XLPE insulated cables [15, 16, 17] further demonstrated the potential of LFDS to assess the condition of thermally aged cables and to link the measured changes in dielectric properties to physical change in the material. It should be noted that only shielded medium voltage cables were considered in these studies.

While the past research reviewed above has demonstrated the ability of LFDS to track thermal and radiation induced degradation in LV cable insulation no data is available for whole cables subjected to aging. The results summarized in this paper address this knowledge gap by presenting data collected on a thermally aged 24 conductors shielded LV control cable representative of cables currently installed in US nuclear power plants. Effect of test configuration, test temperature, test voltage were also addressed in this